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Low NOx Firing System for Tangentially Coal-Fired Boilers Applications Guideline Manual

Combustion Engineering, Inc., Windsor, CT

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LOW NO_x FIRING SYSTEM FOR TANGENTIALLY COAL-FIRED BOILERS: APPLICATIONS GUIDELINE MANUAL

by

A. Kokkinos, R. D. Lewis
Combustion Engineering, Incorporated
Windsor, Connecticut 06095-0500

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Project Officer

David G. Lachapelle
U.S. Environmental Protection Agency
Air and Energy Engineering
Research Laboratory
Research Triangle Park, North Carolina 27711

Air and Energy Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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16. ABSTRACT The manual is a concise user's guide of Combustion Engineering's Low NOx Concentric Firing System. It is based on extensive pilot scale and small and large utility-scale demonstrations, in particular a program completed in May 1984 at Utah Power and Light Company's 400-MWe Hunter Unit 2 station. It addresses six points for the user to evaluate to determine the applicability, feasibility, and cost of installing the concentric firing system to a particular steam generating unit: (1) rationale, (2) applicability, (3) pre-design evaluation, (4) design, (5) performance optimization and evaluation, and (6) economic analysis. The manual follows the final project report (a case study example of retrofitting this technology) for the Hunter Unit 2 utility demonstration program.

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Coal	Stationary Sources	21D
Combustion	Low NOx Concentric	21B
Boilers	Firing System	13A
Utilities		
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This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

This applications manual presents a concise user's guide of Combustion Engineering's Low NO_x Concentric Firing System. This guide has resulted from extensive pilot-scale and small and large utility scale demonstrations. In particular, a demonstration program of this system was completed in May of 1984 at the 400 MWe Hunter Unit #2 station of Utah Power and Light Company.

The applications manual addresses six points for the user to evaluate to determine the applicability, feasibility, and cost of installing the concentric firing system to their particular steam generating unit. These six points include (1) rationale, (2) applicability, (3) pre-design evaluation, (4) design, (5) performance optimization and evaluation, and (6) economic analysis.

This manual has been issued subsequent to the final project report for the above mentioned utility demonstration program. The report is titled "Field Evaluation of a Low-NO_x Firing System for Tangentially Coal-Fired Utility Boilers," EPA Report Number 600/7-85-018. This report should be referred to for a case study example of retrofitting this technology.

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1.0 INTRODUCTION

A long-term, large-scale utility demonstration of the concentric or offset firing system was completed in May 1984. This demonstration was sponsored by the Environmental Protection Agency under Contract No. 68-02-3655 and was the culmination of research efforts sponsored by both Combustion Engineering, Inc. and the EPA. The principal objective of this research and demonstration was to reduce NO_x emissions from tangentially coal-fired steam generators without adversely affecting unit efficiency or performance. This objective was met during the full-scale demonstration and, in addition, applications of this technology to other steam generators have presented other operational parameters which can be affected/improved upon its installation. The affected areas include steam temperature control, waterwall slagging, and the superheater/reheater steam outlet temperature relationship.

The first two sections of this report develop the general rationale and applicability of the process. This is done by presenting the areas of boiler performance and emissions potentially affected by the concentric firing system and permits the potential user to ascertain the applicability of the technology to his particular needs. Additionally, the general requisites of the concentric firing process with respect to the firing system and auxiliary equipment systems design have been developed. This allows the designer to evaluate the technical feasibility of applying the process to his particular steam generator.

The third and fourth sections of the guideline manual extend and develop more detailed system requirements and the design details for the concentric firing system. Included in these sections is the requirement to establish a unit characterization. This characterization would be necessary for both new and retrofit applications of this technology. It is used to determine existing or design load patterns, excess air levels, pulverizer operating patterns, windbox damper operation, slagging tendencies, boiler turndown, steam temperature control, actual or anticipated unit emissions, fan and unit performance.

Then, based on this characterization, the various options or arrangements available with the concentric firing system are considered. These options include modifications to windbox compartment free areas, coal compartment and nozzle configuration, and fixed versus variable horizontal offset.

The fifth section of the guideline manual discusses the recommended procedure for optimization of the system upon its installation. The optimization would involve recharacterizing the unit's performance and emissions by conducting a short series of parametric tests and close observation of the longer term operating trends.

The final section addresses the economic viability of the concentric firing system. The analysis is conducted utilizing the Electric Power Research Institute (EPRI) economic premises. It covers new and retrofit applications for utility size steam generators. The analysis can be directly applied to bituminous-type coal firing plants, and for applications of the cost analysis to lignites and sub-bituminous coals the impacted areas have been identified.

2.0 CONCLUSIONS

- NO_x emissions from tangential coal fired boilers may be reduced by more than 40 percent by a combination of overfire air, flame retention, and concentric firing. The significant NO_x reductions achieved with concentric firing, were accomplished in conjunction with overfire air to reduce the bulk lower windbox (furnace) stoichiometry.

- Boiler performance has been shown to be beneficially affected with concentric firing. The principal effect has been a reduction in the slag accumulation thickness and/or a drier more friable slag deposit on some boilers. Also, on some boilers a reduction in the superheat and reheat spray flows has been seen. These two effects appear to be very coal dependent and should be evaluated on a case-by-case basis.

- The concentric firing system is technically retrofitable on most tangential coal-fired or multifuel boilers. In many cases it can be applied as part of a normal windbox maintenance program.

- The cost of installing a concentric firing system is dependent on the unit size, coal type, and existing firing system configuration. The total capital requirements (1985 dollars) have been estimated to be between one and four dollars per kilowatt ($1-4/KW).

3.0 DISCUSSION

3.1 RATIONALE

This section presents the general trends and effects on unit performance and emissions that a concentric firing system installation may have on a steam generator. This system has already been applied to units firing Western, Midwestern, and Eastern bituminous coal types. This section also delineates the potential effects of the coal nozzle tip flame diffuser modification. From these applications it has been determined that in most cases these systems can have a favorable effect on NO_x emissions, waterwall slagging, and steam temperature control via reductions in the superheater and reheater attemperating sprays. It has also been shown that the system is easily retrofitable and may be installed as part of a regular maintenance program within scheduled outage periods.

3.1.1 NO_x Emissions

With respect to NO_x emissions, units characterized both without the system (baseline) and with the system have shown the following results. For a high volatile Western bituminous application the combined results of concentric firing, ignition point flame retention with coal nozzle tip flame diffusers, and overfire air, lowered NO_x emissions by about 40 percent. The first two processes accounting for an approximate 8 percent reduction each and the overfire air reducing NO_x the remaining 23 percent. It was also shown that overfire air should be used in conjunction with the concentric firing system to achieve optimal NO_x reductions. That is, the NO_x reductions achieved when firing without overfire air were due primarily to the coal nozzle tip flame diffusers. The third principal result shown was the linearity of the NO_x reduction upon lowering the excess air level. This was evident with or without the concentric system and/or overfire air. The NO_x reduction for reduced excess air firing was approximately 10 percent per every 1 percent reduction in the flue gas oxygen level. From these results it was concluded that NO_x emissions should be preferentially reduced by (1) lowering the bulk

lower furnace stoichiometry with minimum excess air and overfire air, (2) quickly establishing a stable ignition front in a reducing atmosphere with the flame diffusers, and (3) maintaining the reducing atmosphere as long as possible by utilizing concentric firing.

One Midwesten bituminous application of concentric firing produced NO_x emissions reductions of between 24 and 36 percent for normal operations and up to 40 percent for simulated overfire air operations. This application may have had higher NO_x reductions than the Western bituminous program because of the decreased waterwall slagging exhibited with the concentric firing.

3.1.2 Waterwall Slagging

Further comparison of these two units and their coals showed that the Western bituminous unit had light to moderate slagging tendencies. It fired a relatively low iron coal with little ash fusion temperature difference between reducing and oxidizing atmospheres. The Midwestern bituminous unit was an industrial design used by a municipal utility. It had no reheater and had heavy slagging tendencies. Its coal ash had a relatively high iron content and low iron oxide to calcium oxide ratio. It also had a larger difference between oxidizing and reducing atmosphere ash fusion temperatures. Therefore, relating to the previous section, the greater NO_x emissions reductions on the Midwestern unit may have been due to the combined effects of concentric firing and lower furnace temperatures.

The effects that the concentric firing system had on slag reduction were further confirmed at the Midwestern unit by visual observations and decreases in desuperheat spray flow. Applications on two other Midwestern units and a second Western unit showed similar results. These customers purchased the concentric firing systems as commercial equipment rather than R&D projects, as such they wish to remain anonymous. Operators at several of these other units commented that prior to the modification they were either load-limited due to running slag or had to drop load daily to shed slag. Upon installating the concentric firing system these problems were reduced.

Therefore, applications of concentric firing to boilers which have a slag that is improved (greater friability or higher ash fusion temperature) in oxidizing atmospheres could be benefitted by its installation. And, for applications of concentric firing to lightly slagging boilers or for boilers firing coals unaffected by oxidizing atmospheres, there will be only minimal changes in the furnace heat absorption and slagging tendencies. The Western bituminous lightly slagging unit showed a slight increase (approximately 10° to 20°F in the horizontal furnace outlet gas temperature FOT) due to the combustion staging.

The flame diffusers had a negligible effect on slagging for the Western bituminous light slagging application. Other applications of the flame diffusers have had the same minimal effect and therefore most applications are expected to have minor changes in slagging tendencies with the flame diffusers.

3.1.3 Steam Temperature Control

As stated above, the concentric firing system can affect the steam temperatures directly by staging the combustion or indirectly by changing the waterwall slagging. Relating these effects to the particular changes occurring on an individual boiler requires an analysis beyond the scope of this project due to the variety of surfacing arrangements. However, based on the installations tested thus far, some general trends have developed. For installations which only develop light slag accumulations on their waterwalls, or which have slag compositions which are unaffected by changes from reducing to oxidizing atmospheres, a slight increase (less than 5°F) in the superheater steam outlet temperature is anticipated. This would be caused by the increased FOT due to combustion staging. The reheater steam outlet temperature would typically not be as affected as the superheater for this change in the FOT. A slight (less than five degrees (5°)) lowering of the burner tilt position may result from this modification to counteract the increased reheater steam outlet temperature. Or equivalently, for units which do not have vertical tilting capability or for units which already operate at the design superheater steam outlet temperature there will be a slight increase in the desuperheat spray flow.

For units which have heavy accumulations of waterwall slag and/or have slag compositions which are affected by changes in their oxidation state, the steam temperatures are more greatly affected. For these applications there has been a significant reduction in the slag accumulation and subsequent increase in the lower furnace heat absorption. That is, while the rate of buildup may not have changed the deposits they have become more evenly distributed and have become drier, more friable and more easily controlled. The result is that this reduces the horizontal furnace outlet temperature and lowers the superheat and reheat steam temperatures. Or alternatively, the attemperating steam spray flows will decrease. This reduction in waterwall slag and lower FOT more than compensates for any FOT increase that may be caused by staged combustion. Operators at one Indiana installation reported that slag reduction caused increases in flyash flow of approximately 25 percent. This unit also exhibited a concurrent reduction in its desuperheat spray flow.

During the 400 MWe Western bituminous demonstration, an additional windbox modification was made which also affected the steam temperatures via altering the normal position for the burner tilts. This modification consisted of installing the coal nozzle tip flame diffusers as described in Section 3.1.1. For this light slagging application, the burner tilt change was approximately 10 to 15 degrees upward. This tilt change is an automatic response to counteract an approximate 40°F reduction in the horizontal FOT. If the burner tilts had not compensated for this 40°F reduction in the FOT, a superheater steam outlet temperature drop of less than 10°F would have occurred (assuming similar total steam flows). Therefore, for this Western bituminous 400 MWe application the combined effects of concentric firing (raises FOT) and coal nozzle flame diffusers (lowers FOT) was negligible.

Currently there have been no tests of the flame diffuser modification on a Midwestern or Eastern coal with a high iron content (high ash fusion temperature differential between reducing and oxidixing atmospheres) or on a heavy slagging unit with slag unaffected by the local atmosphere. However, it is anticipated that the quicker ignition stabilization due to the flame diffusers will increase the lower furnace total heat release. The cause of this increase in the heat release will determine the overall effect on slagging

and steam temperatures. If this increase is caused by a shifting down in the heat release zone with no change in the release zone height (similar to lowering the burner tilts) then the slagging patterns will shift downward with little difference in their accumulation rates. This type of operation will subsequently lower the furnace outlet temperature and lower the superheater and reheater steam temperatures or attemperating spray flows. If, however, the higher heat release in the lower furnace is caused by a shortening in the release zone height,then the lower FOT and steam temperature will be only temporary. The reason for this change being only temporary would be the higher local flame temperatures detrimentally increasing the local slagging and eventually reducing the furnace heat absorption. This would eventually cause the FOT and steam temperatures to rise.

Based on the current testing of the flame diffusers it is felt that the primary effect of the diffusers is on the location of the ignition front and only minor effects on the furnace turbulence. Therefore, the principal effect of the flame diffusers on flame shape and location should be a shifting in the flame envelope with no change in the release zone height.

To summarize, for a light slagging coal the concentric firing system will not effect slagging and will slightly increase the furnace outlet temperature and/or steam temperatures. The flame diffusers will depress the FOT and steam temperatures slightly. Combining these modifications will result in a negligible effect on the steam temperatures. For a slagging unit which has a slag minimally changed by reducing versus oxidizing atmospheres the concentric firing system will only minimally effect slagging and steam temperatures. The flame diffusers, though not quantified, should reduce the FOT and steam temperatures. For a high iron type coal or one which is significantly affected by changing from a reducing to an oxidizing atmosphere, the concentric firing system should reduce slag accumulations, steam temperatures, and/or attemperating spray flows. And, again, the flame diffusers should reduce the FOT and steam temperatures.

3.1.4 Retrofitability

Installations of the concentric firing system and the coal nozzle tip flame diffusers have thus far been achieved with nozzle tip for nozzle tip replacements. Both modifications have been installated during normal annual maintenance outage timeframes. As will be further discussed in Sections 3.2, 3.4, and 3.5, the flame diffuser modification can be retrofitted to more than 95 percent of the existing tangential coal firing steam generators. The concentric firing system can be installed, at least partially, on greater than 95 percent of the coal-only tangentially fired boilers. Of the multifuel boilers, approximately 50 percent are viewed as retrofitable with the concentric firing system. Both modifications can be done for minimal incremental cost. That is, a minimal cost differential between the modified coal nozzle tip and auxiliary air nozzle tips and the costs for maintenance/replacement of a standard nozzle tip. Several current retrofit applications of the concentric firing system have been installed by the utilities' own personnel.

3.2 GENERAL APPLICABILITY

The concentric firing system modification and the coal nozzle tip flame diffuser modification have been developed for applications to tangentially coal-fired steam generators. These modifications are directly applicable to both industrial and utility size tangentially fired boilers of both single and multicell furnace design.

The many varying industrial unit configurations have not been reviewed for this study, however, their retrofit feasibility will follow the same constraints and patterns as determined in this utility boiler study.

A survey of Combustion Engineering's coal-fired utility boilers inclusive of those sold between 1960 and 1982 was recently completed. (The survey was done for EPA Contract 68-02-3915 which is currently in progress.) The survey showed that a total of 273 coal-designed units had been sold. Of this total, 223

represented the domestic utility market. The coal-only and the multifuel shares of the domestic utilities are 178 units and 45 units, respectively.

It has been estimated that greater than 95 percent of the 178 coal-only units could be retrofitted with the concentric firing system. However, of these 169 units, several have refuse firing compartments and many have multiple oil or gas warm-up elevations and, therefore, can only be partially retrofitted with the concentric firing system. Currently, eight (8) units have been retrofitted. Based on the configurations of the oil and natural gas firing compartments in multifuel boilers it has been estimated that approximately fifty (50) percent of the multifuel boilers can be retrofitted.

The flame diffuser modification is applicable to more than 200 of the coal firing domestic utility boilers including both the single fuel and multifuel types. The remaining coal-firing boilers are not deemed feasible because of specially designed coal nozzle tips.

Evaluating the applicability of the modifications is also related to the rationale of its installation as stated in Section 3.1. With respect to NO_x emissions, it is recommended that the unit also have overfire air capabilities. Overfire air compartments for NO_x control currently exists on 91 units and are conceivable on the remaining coal firing boilers. (Refer to EPA Report EPA-600/7-77-117.)

Also, the applicability will be determined from the coal, ash, and slagging tendencies for both retrofits and new units. As shown in Section 3.1 the modifications effects vary from one coal and ash type to another.

And, as with any modification, economic considerations will determine the applicability of the modifications. However, in addition to the normal considerations of plant age, useful life of the modification and capital requirements, the potential effects that the modifications have on slagging and steam temperature control must be considered. That is, reductions in slagging could restore lost generation capacity on heavy slagging boilers and limit the load reductions and associated thermal cycling used to shed slag

accumulations. And, changes in steam temperatures and/or tempering spray flows will effect (beneficially or detrimentally on a case by case basis) the turbine heat rate. These economic considerations are more fully covered in Section 3.6.

3.3 PRELIMINARY DESIGN REQUIREMENTS

A specific unit characterization would be required to further determine the applicability and define the design parameters for either the concentric firing system modification or the flame diffuser modification. The design of both modifications can be impacted by the windbox and boiler operation (or perceived operation for a new unit). For example, a unit base loaded at maximum continuous rating (MCR) would have a greater percent of the total air flow offset with the concentric firing system than a unit operated at reduced load. Also, many older units have very conservatively designed windboxes which operate at a lower than optimum auxiliary air-to-fuel air ratio. It may also be desirable to alter the combustion air jet velocities to achieve optimum performance with the flame diffusers and concentric firing system. This will effect the secondary air system pressure drop and, therefore, the forced draft fan performance and limitations must be evaluated. Thus, it is recommended, though not required, that a unit performance and characterization test be performed during the preliminary design phase of an application.

At a minimum, operations data logs should be reviewed to determine the normal unit loading schedule, sootblowing schedule, excess air versus load, windbox damper position versus load and excess air, fuel firing elevations versus load, and steam temperatures and tempering spray flows.

A characterization test would also provide information on unit emissions, lowest permissible excess air, air flow distribution, and the unit slagging and fouling characteristics. It could also highlight unit specific operating problems which could affect the design.

Also, based on the tests conducted thus far, if the goal of the modifications is to reduce NO_x emissions, then overfire air should either exist currently

or it should be installed as part of the modification. For the units existing with existing overfire air, its operation and effects on windbox controls should also be characterized.

3.4 DESIGN CONSIDERATIONS

Several configurations currently exist for the concentric firing system. The particular configuration utilized will depend both on the rationale and purpose of its installation and upon the physical constraints of the windbox. The primary emphasis of the installations made thus far have been either for NO_x emissions reductions or slag control. However, as stated in Section 3.1, recent testing of these units has shown that the concentric firing system has the potential to improve low load flame stabilization and unassisted burner turndown and it also may effect superheater and reheater steam temperature control.

The three primary physical configurations of the concentric firing system which must be considered include:

1. Fixed Horizontal Offset
2. Variable Horizontal Offset
3. Use of Flame Holders

The advantages of the fixed horizontal offset design over the variable offset design include reduced material and fabrication costs and lower installation costs. Also, the elimination of the horizontal offset drive linkages and fewer moving parts will result in simpler operation. A generic sketch of the fixed offset design is shown in Figure 1.

The variable horizontal offset design as depicted in Figure 2 also offers several advantages. The additional flexibility will provide the means necessary to optimize the offset angle for maximum NO_x reduction, maximum slag reduction, and efficient boiler performance. It is currently judged that this offset angle flexibility would be required for dual fuel (oil and coal or

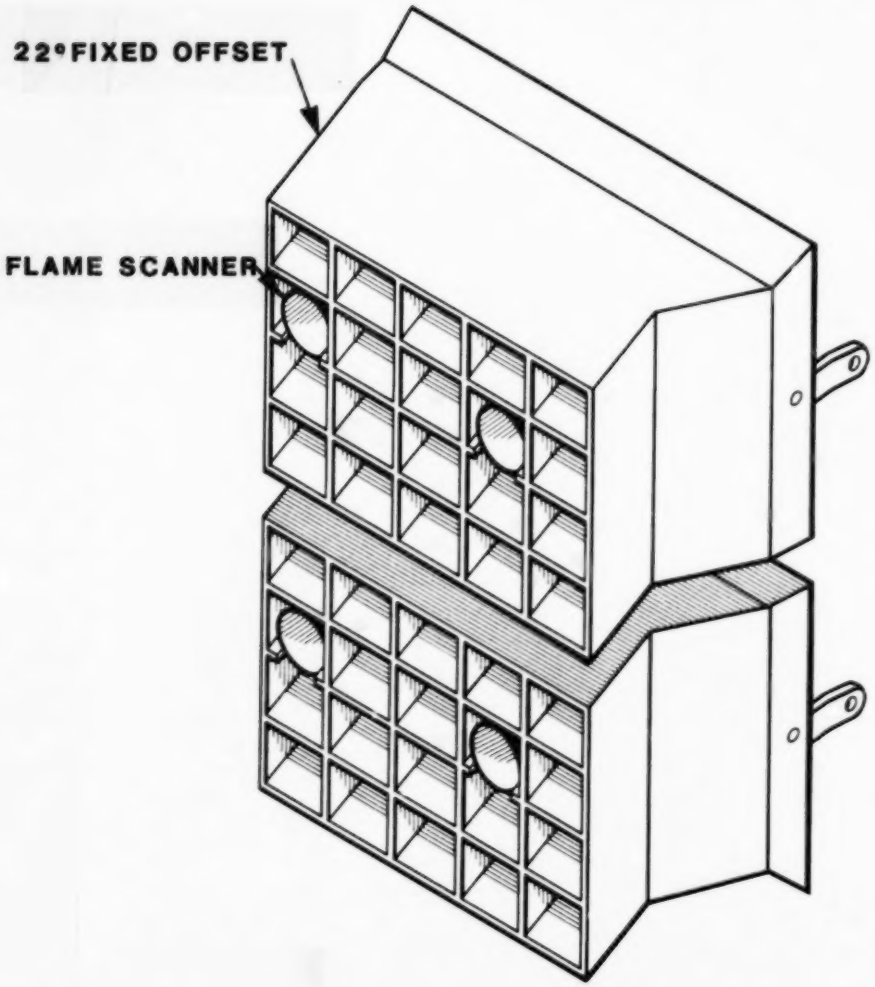

Figure 1. Fixed offset auxiliary air nozzle tips for the concentric firing system.

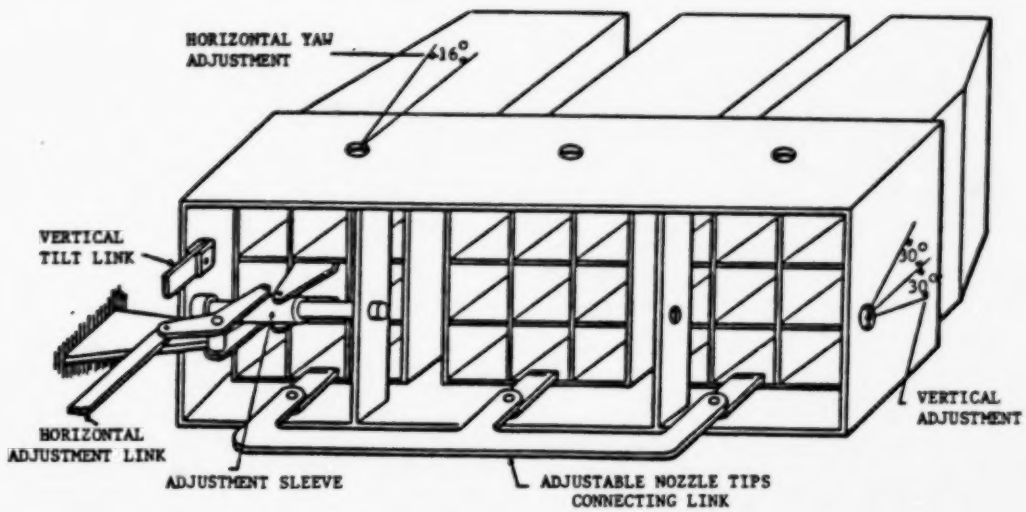

Figure 2. **Typical arrangement for horizontally and vertically adjustable air nozzle tip.**

gas and coal) applications of this system. The purpose for this requirement is that the effect of offset firing on oil and gas burning has yet to be determined.

Tests which varied the offset angle have been conducted thus far on two boilers. One test showed a significant relationship between the angle of offset and the NO_x reduction capability of the system. This test was conducted on a boiler which had a moderate-to-high level of furnace waterwall slagging prior to the concentric firing system installation. The second boiler tested for performance changes resulting from variations in the offset angle showed only minimal changes upon varying the offset angle. This boiler had only minimal accumulations of waterwall slag in either the baseline or concentric firing mode. Therefore, it is recommended that the variable offset angle design be utilized in cases where heavy waterwall slagging currently exists.

Use of the flame diffusers as shown in Figure 3 is recommended for most applications. They have been shown, in varying degrees, to reduce NO_x, to improve flame stability, and to improve unassisted burner turndown.

The air and the fuel jet velocities and the air distribution would also be considered during the design phase. On new units, current design standards would be utilized. On retrofit applications the current (and/or anticipated) operating conditions of the windbox components, as determined during the characterization, would be factored into the design. The important operating parameters include boiler loading, excess air, windbox damper position, and the use of overfire air.

The material specifications for the offset auxiliary air nozzle tips have been based on high temperature furnace operating experience. The material specified currently for plate components is Type 309 stainless steel. This material has a higher continuous operating temperature rating than the previously specified Type 304 SS. The Type 309 SS has similar high temperature oxidation and corrosion resistance to the Type 446 SS that was used for the full scale demonstration at Utah Power & Light Hunter, but has been shown to exhibit better high temperature strength. The fabricated coal nozzle tips have similar

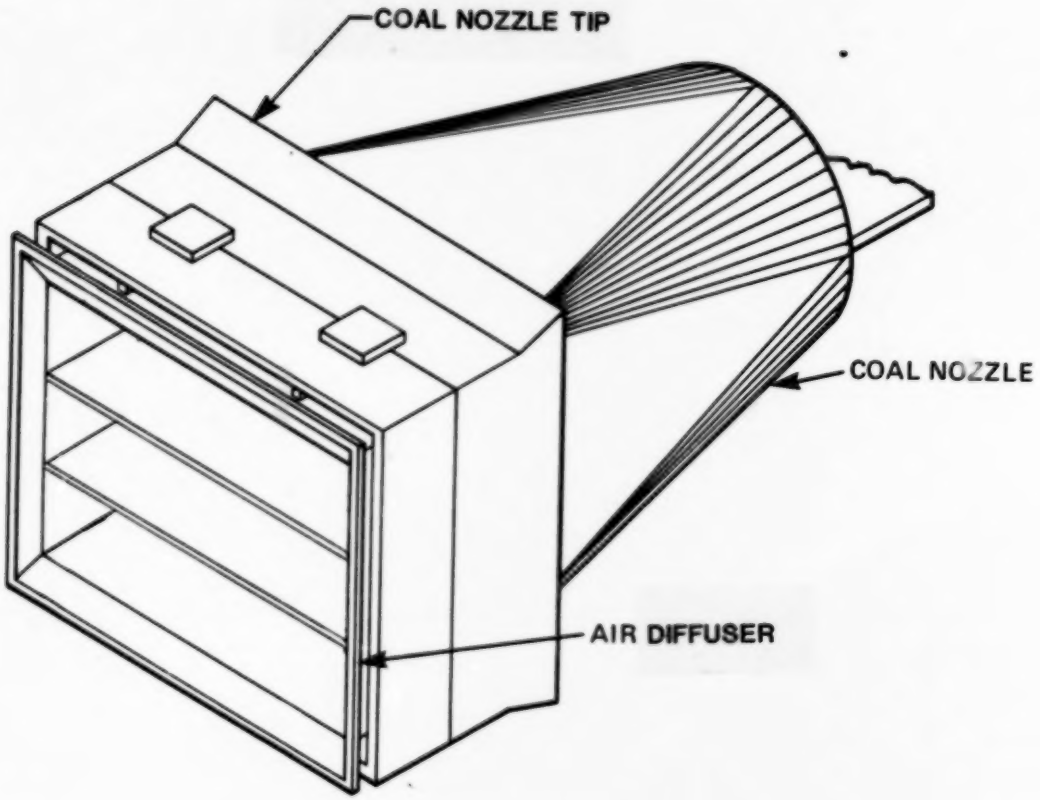

Figure 3. Coal nozzle and nozzle tip with flame (air) diffuser or flame holder.

material specifications and include ceramic components in areas where erosion may occur. Linkages and other components located inside the windbox and not subject to the furnace temperatures are fabricated of carbon steel.

Installation of the concentric firing system simply requires replacement of the existing coal and auxiliary air nozzle tips. This requires either a sky climber/boatswain's chair or scaffolding to the top of the windbox inside the furnace. On the outside of the windboxes the casing, oil guns, scanners, and fuel nozzles need to be removed. This work would typically be done during a three or four week annual maintenance outage, utilizing two work crews one or two shifts per day. (A second shift would be utilized to expedite installation though not typically required.) Installation of the horizontally variable offset design may require some very minor changes to the linkages and vertical tilt bearing locations. It also will require mounting a bell crank mechanism on the outside of the windbox to adjust and set the horizontal offset position.

Maintenance of these windbox components is minimal. The auxiliary air nozzle tips can last upwards of ten or more years provided sufficient closed damper leakage air space is set around the windbox entrance louver dampers. The coal nozzle tips will require more frequent replacement. Their replacement frequency will depend on use, total coal ash content, and coal and ash abrasivity. Typically, some reworking of high wear areas is required on high use fuel elevations annually. On lesser used elevations or low abrasion coals some reworking may be required after two years of service. Replacement of coal nozzle tips may be required for every three to five years of service. On-hand spare parts recommended for the coal and auxiliary air nozzle tips should be approximately one complete elevation of each. Also, a spare set of linkages, pivot bearing, clevis pins, and assorted lock nuts should be available.

To summarize, the installation, maintenance, and spare parts inventory should be similar to standard tangential firing windbox components. Also, as noted previously, for NO_x reduction objectives, overfire air should be part of the firing system design.

3.5 POST-INSTALLATION OPTIMIZATION

Upon installing a concentric firing system on a unit it is recommended that some optimization testing be conducted. The amount of testing would be determined by the objectives of the installation. For NO_x reduction installations, full-load flue gas emissions testing and boiler efficiency testing should be conducted as a minimum. It would also be desirable to examine emissions and boiler performance over the operating load range, excess air range, and burner tilt range. Also, to optimize NO_x reductions the windbox combustion air distribution (including overfire air and overfire air tilt) should be examined. This type of testing would require about a two to three week test period. For the variable horizontal offset design, testing to determine the optimum horizontal offset is also recommended.

Optimization testing would also be recommended for installations where reductions in furnace slagging or changes in boiler turndown capability are the installations objectives. However, for these objectives, long-term operational changes will also have to be examined. For these tests the same variables would be looked at (load, excess air, windbox air distribution, etc.), but for these tests the control parameters would be changes in the slagging and/or boiler heat absorption profiles and flame scanner operation at low loads. The goals being to minimize slagging and optimize the heat absorption profile. The nature of these tests requires long-term observations. That is, though the short-term tests can determine the optimal firing arrangement, they cannot optimize changes in sootblowing frequency, slag shedding load drops, and the operating frequency of the flyash and bottom ash conveying systems. For these types of changes the plant engineers and the boiler operators at the installation site would have a key role in determining how to modify their current operating procedures to best utilize the combustion system modifications.

3.6 ECONOMIC CONSIDERATIONS OF CONCENTRIC FIRING

The successful demonstration of concentric firing at Utah Power and Light Company's 400 MWe Hunter No. 2 Generating Station and on several other boilers

has shown the technical feasibility of retrofitting this system on tangentially fired boilers. The cost of providing this system is strongly dependent on the number of fuel firing elevations in each windbox and on the number of windboxes in the furnace. That is, the material costs of the concentric firing are in near direct proportion to the number of fuel admission assemblies. (A fuel admission assembly consists of a coal nozzle and coal nozzle tip, the fuel compartment secondary air tips and the adjacent auxiliary compartments secondary air tips.) The per assembly installation costs (and to a minor extent material costs) will decrease slightly for large, divided, or multi-furnace boilers.

For this study, a single-furnace four windbox arrangement was analyzed. The fuel type was bituminous coal with a nominal "as received" analysis of 10 percent ash, 10 percent moisture, and a higher heating value of 11,000 Btu per pound. Divided-furnace systems will have approximately double the cost of single-furnace systems. Lower quality coals can impact the system costs because of a greater number of fuel elevations for a similar boiler rating.

The process capital costs for installing a concentric firing system are presented in Figure 4. These costs represent retrofit applications utilizing the variable horizontal offset design. The significant maximum to minimum cost range is due to various complexities that may exist on a particular unit. These complexities include oil or gas firing in the auxiliary air compartments, number of nozzle tips per auxiliary compartment, and design modifications to accommodate tilt linkages and drives.

The total capital requirements and the incremental busbar power costs have been developed utilizing the "EPRI Economic Premises for Electric Power Generating Plants." An engineering and home office overhead cost equivalent to ten (10%) percent of the process capital was assumed. A project contingency of fifteen percent (15%) of the process capital was utilized based on a Class II estimate classification. A process contingency of five percent (5%) of the process capital was utilized because a full scale module has been demonstrated. The sum of the process capital and these contingencies equals the total plant investment (TPI). The only additional capital requirement was a two percent

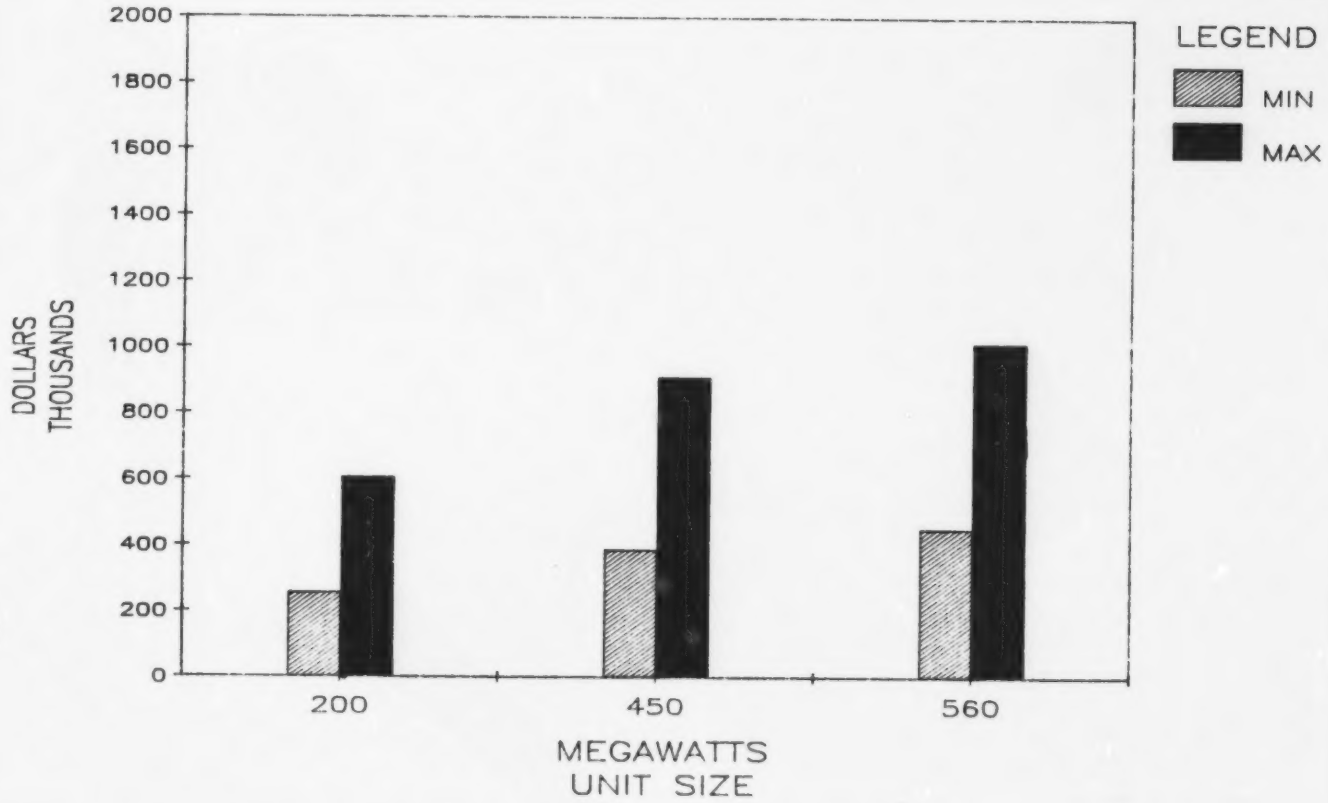

Figure 4. Retrofit process capital costs for the concentric firing system in 1985 dollars.

(2%) of TPI contingency for preproduction and start-up costs and for training the operators in the use of concentric firing. The total capital requirements for concentric firing are shown in Figure 5. The current fifteen year accelerated depreciation method was utilized for determining the levelized busbar power costs. These costs are shown in Figure 6. And, finally, it is stressed that while the economic analysis is based on unit size, the costs have a more direct relationship to the number of firing elevations and windboxes than megawatt capacity.

Against these costs, the following credits should be evaluated on a case by case basis. On units which the concentric firing system and flame diffusers allow stable, unassisted coal firing fuel should be credited. Another potential credit would be the ability to fire at reduced excess oxygen levels. Reducing the excess oxygen reduces the dry gas loss. A one percent reduction in the excess oxygen level increases the boiler efficiency approximately 0.25-0.40 percent. A third potential credit is a decrease in reheat tempering sprays. Studies have been shown that having approximately six percent (6%) of reheat flow as spray detrimentally increases the plant heat rate by about 0.8 to 1.2 percent.

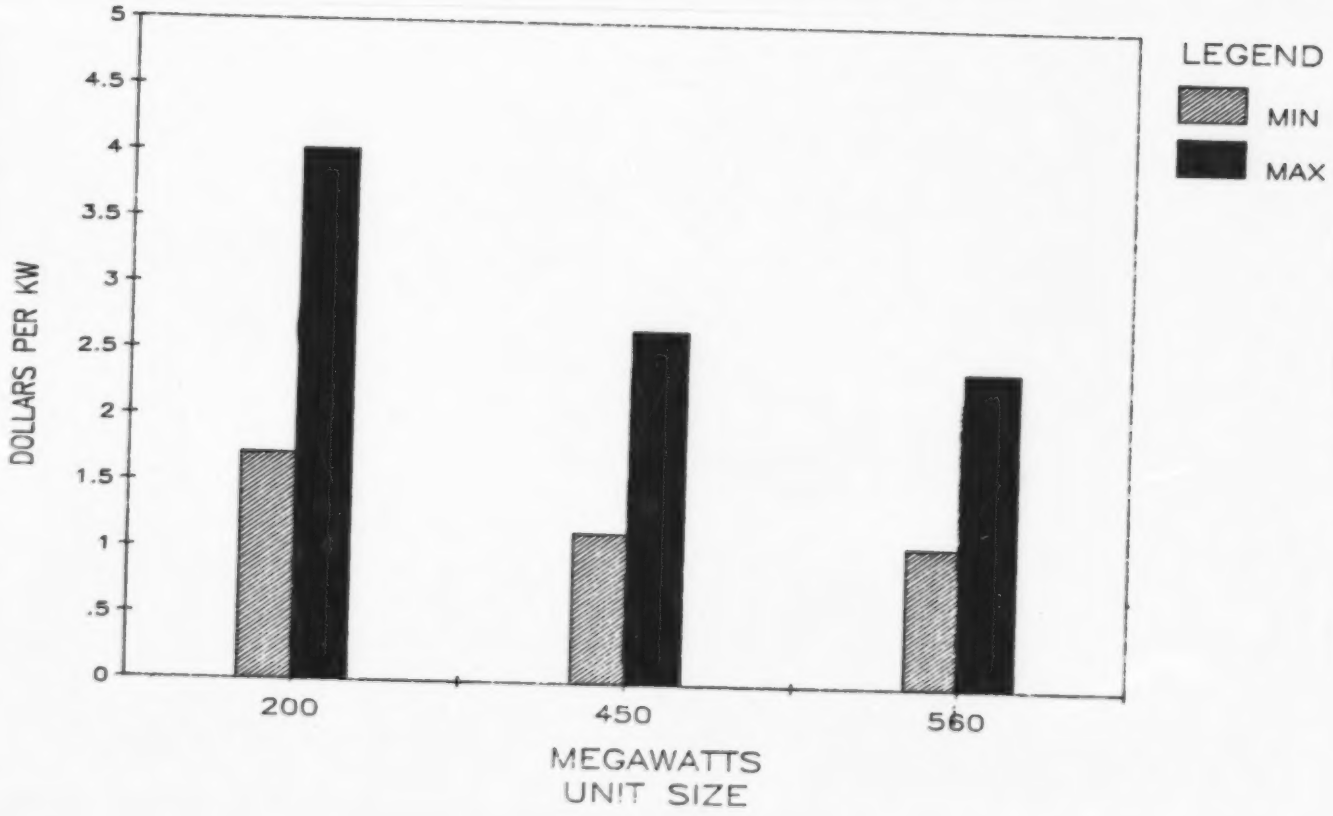

Figure 5. Total capital requirements for retrofits of the concentric firing system, 1985 dollars.

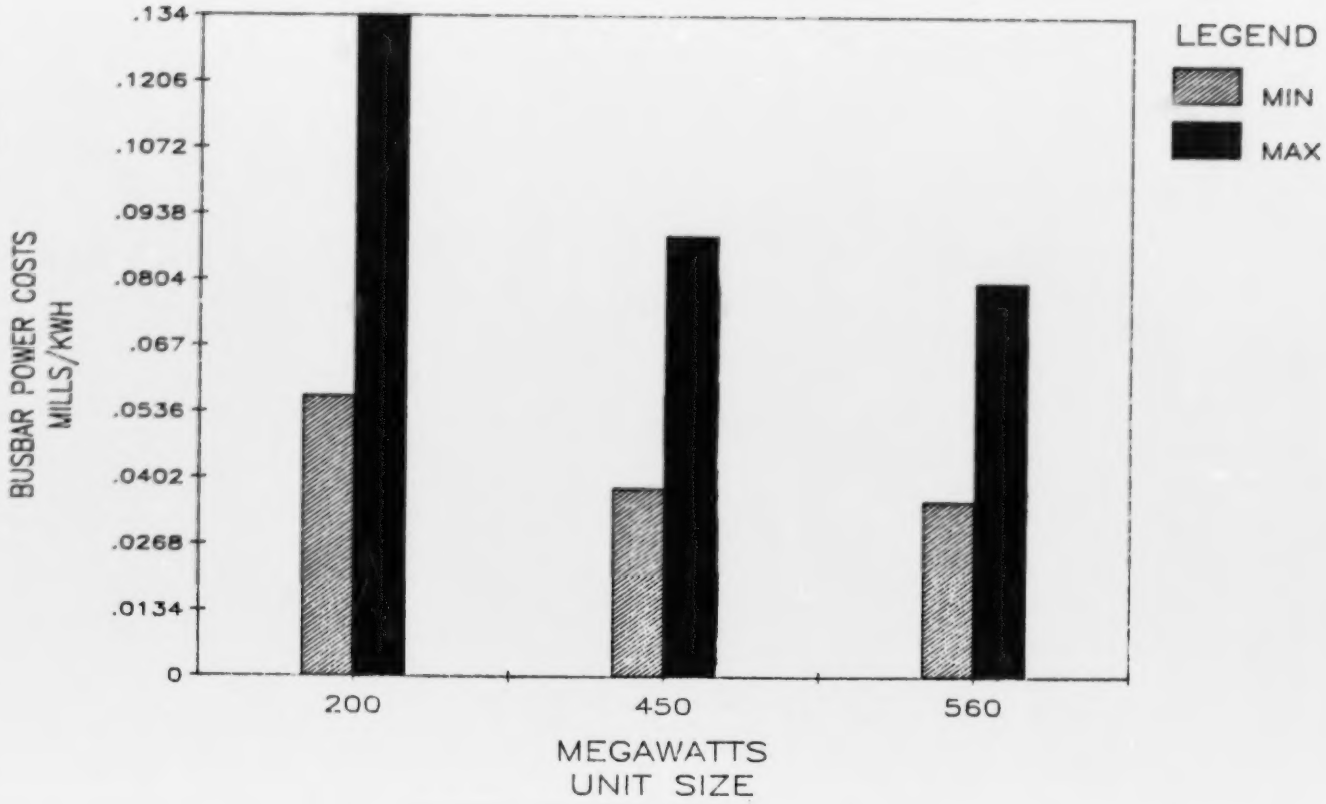

Figure 6. Busbar power cost increment for retrofit installations of the concentric firing system, 1985 dollars.